Applications of Architecture for Future Martian Habitats

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I. Abstract

After the Apollo era of the 60-70s, humans moved to establish colonies on Mars. As precursors to manned Martian missions begin to form, consideration must be given to where humans will live. The objective of this paper is to analyze the problems Mars presents for sustaining human life, and proposing how they could be solved with the Architectural Design of habitats. Living on Mars raises the question of how to solve high levels of radiation, cold temperatures, preservation of key resources, and human psychological effects. Currently, insulating materials are common practice to protect humans from extreme radiation and temperature. Though useful in the protection that they provide, living underground protects against radiation to a higher degree and allows for self-sufficiency by using planetary resources. Space Architecture looks to solve the problems by incorporating nearby materials and using the design of the habitat instead of needing accessory resources. To continue independence, the habitat must also preserve key resources and be highly efficient at doing so. The ability for a colony to be self-sufficient means that the likelihood of survival is dramatically higher. This comes first with the ability to continue recycling air, reusing/purifying wastewater, and growing enough food to sustain the people living in the building. Architecture can look to solve the routing of systems to recycle air and water, but the incorporation of a plant ecosystem into the habitat can solve all three problems simultaneously. Architecture at its base level can be defined as the creation of space for people to live and experience. Beyond taking care of humans physically, the importance of a habitat is to support their mental state. On Mars, humans must have a shared space that can grow along with the crew and create memorable experiences. If humans are to create a colony on Mars, it must have commonalities with the homes that we create on Earth.

II. Introduction

In our Solar System, Mars is the closest planet that is readily capable of supporting human life in the near future. Mars currently offers humans their two basic needs of water which can be excavated and oxygen which can be removed from its atmosphere. Nowhere else in the solar system do both of these elements occur on a planet besides Earth. The potential for humans to live on Mars is there, but a vast majority of other problems currently bound humans to earth. However, the starting point for living on Mars is clear: shelter.

Problems such as high levels of radiation, temperature, water/air preservation, and psychological effects can all be addressed by the design of the habitat. Martian Architecture will look to solve a vast number of problems never experienced on earth, and will eventually take on a style of its own because of this. Earth will be a reminder of how humans used to live, while Mars will be an image of where we are to go.

Over thousands of years, humans have developed an architectural style that has greatly improved upon the designs of the ancestors. Humans have learned to design structures with extreme complexity, but have not forgotten to design with significance and meaning. A shelter that has meaning is no longer just a place to live, but a settlement or home. To design buildings with these aspects humans have looked to Vitruvius' Triad of Architecture: durability, usefulness, and beauty. As humans look to fulfill their impulse for exploration by living on other planets, architectural considerations must be made when developing a new home for humanity. Those of which must look to solve the dangers posed to humans, but also inspire a new chapter of humanity to establish Mars as their new home.

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III. Problems for Human Survival on Mars

A. High Levels of Radiation

On Earth, solar radiation is usually not considered a dangerous factor to be affecting humans. Due to Earth's magnetosphere, the majority of ionizing radiation is captured before it ever reaches the surface. The effects of radiation on Mars, however, are very noticeable. Roughly 4.2 million years ago Mars lost its magnetic field and has been bombarded by heavy radiation since.

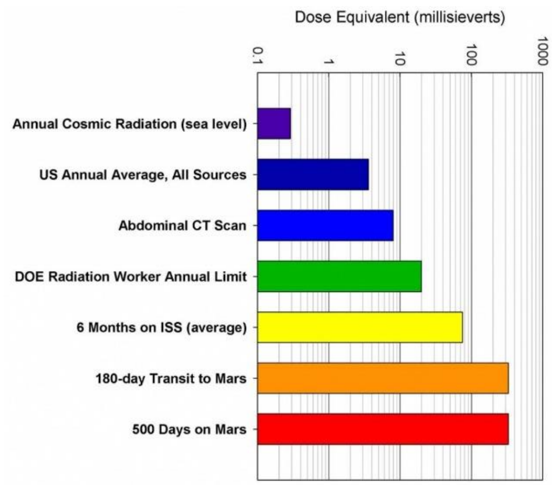

Fig. 1 Mars Curiosity Rover Radiation Exposure Comparisons [1]

During the Curiosity rovers first 300 days it was exposed to roughly 0.67 millisieverts (33.5 rem) per day as shown in Fig. 1 [1]. To protect astronauts from severe radiation exposure, NASA created a limit on the number of rems an astronaut cannot exceed. This includes a range from 100-400 rems depending on age and no more than 50 rems in an annual period. On Earth the normal dose of radiation a human is exposed to is 0.62 rem [2]. Humans being exposed to this much radiation will have drastically reduced time spent on Mars, along with an increased chance for life-threatening health problems. For humans, these levels of radiation can cause extreme problems to bodily systems. High exposure over a long period of time can lead to [3]:

- Cancer
- Death of nonregenerative cells/tissue
- Genetic damage
- Impact on fertility
- Suppression of immune function

These levels of radiation have not been fully experienced on Earth and have the possibility of crippling the first humans to explore Mars. Since there is no natural protection against radiation on Mars, the habitats humans live in must be designed to.

B. Extreme Cold Temperatures

Earth has been able to support life for millions of years due greatly impart to its dense atmosphere and relative location to the sun. When Mars lost its magnetic field it also began to lose its atmosphere. The loss of its dense atmosphere has resulted in a rapid cooling of the planet and the inability to retain heat.

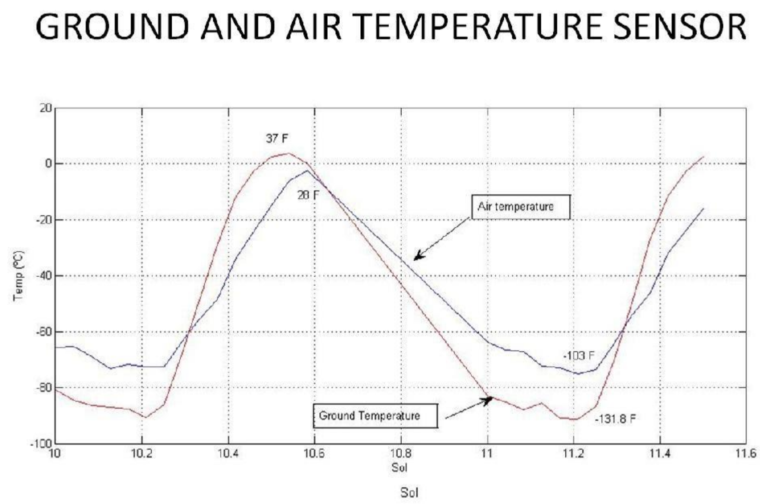

Fig. 2 Air and Ground Temperatures on Mars [4]

As shown in Fig. 2 the surface temperature can range from 37 F during the day to -131.8 F during the night, though temperatures can become even lower at different seasons on Mars [4]. These conditions are inhospitable to humans and any other plant life to be used as crops. Though the temperatures are extremely low, the heat transfer is low due to Mars' atmosphere not being dense. The Architectural design of the habitat must ensure the preservation and production of heat when in low temperatures using adequate insulation. Otherwise, water needed for the habitat could freeze, plants for food could die, and the crewmates would not be able to produce the necessary heat to keep them alive.

C. Production and Preservation of Key Resources (Air, Food, Water)

To sustaining human life, the building blocks are oxygen, water, and food. Unlike Earth, Mars does not have either of those readily available. Over the past decade, discoveries have been made leading scientists to believe that there is liquid water on Mars, however, this is still not readily available as it will take time to locate these "lakes" and begin excavation. The only confirmed source of water on Mars is in its poles in the form of ice as seen in Fig. 3.

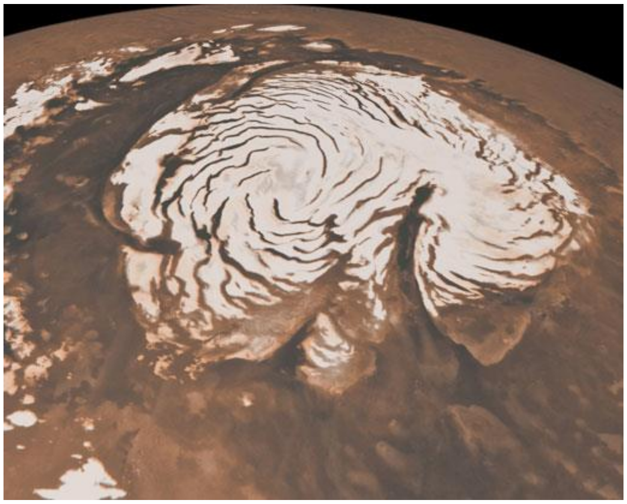

Fig. 3 Mars' Northern Ice Cap [5]

The excavation of ice to use as water for a colony is a long-term solution to create an independent colony. However, as humans begin to first settle Mars this is an unlikely short-term goal. The Habitat that humans are to live in must be built to be sustainable in every aspect as to maintain as much water as possible.

Mars		**Earth**	
Carbon Dioxide (CO_2)	- 95.32%	Nitrogen (N_2)	- 78.08%
Nitrogen (N_2)	- 2.7%	Oxygen (O_2)	- 20.95%
Argon (Ar)	- 1.6%	Argon (Ar)	- 0.93%
Oxygen (O_2)	- 0.13%	Neon (Ne)	- 0.002%
Carbon Monoxide (CO)	- 0.08%	Helium (He)	- 0.001%
Water vapour	1 –2 km³	Water vapour	13,000 km³

Fig. 4 Mars/Earth Atmosphere Comparison [6]

Without oxygen, there is no possibility of survival for humans. However, as shown in Fig. 4 the oxygen makes up less than 1% of the total Martian atmosphere [6]. In the same way as water, there is no direct way to capture this oxygen. The design of the habitat must be efficient at maintaining this precious element, but also incorporate designs to produce its own in case of an unseen event.

Mars' environment provides a hostile place for any life, this creates a very difficult problem for agricultural production. Without an adequate temperature, soil, or atmosphere for plants to grow colonists will have to rely solely on supply missions for food. This creates a dependency on earth that might result in the colony being ill-prepared to handle catastrophic events. What creates independence is the ability for the colony to sustain itself in every aspect, the design of the habitat be able to provide enough food to support every person that lives within it.

D. Social and Psychological Effects

The first Mars crew will be the humans to test what psychological effects weigh on a person after leaving their home planet. Though the astronauts chosen for this mission will be mentally tough, it is not understood how the human brain will react. To create an environment on Mars that is supportive for humans there must be a habitat that tries to adapt aspects of earth to fit a new world. Martian Architecture must create spaces that try to bring social interactions and customs to mars as a way to connect the crew. Most importantly it must be designed in such a way that is comforting to the people who live in it and reminds them of home. A new "home" should be made by the crew who lives inside it. The spaces they share should be conducive to creating new memories and able to be decorated by the crew to fit their vision of "home."

IV. Use of Architecture in Solving Martian Problems

A. Radiation

1. Water Tanks

Hydrogen is extremely efficient in protection against radiation, this makes water a great radiation shield for both spacecraft and habitats [7]. The architectural design of the habitat could be used to incorporate the wastewater tanks into usable radiation shields. Using the already necessary tanks as radiation shields would allow for a major reduction in radiation reaching the humans inside. This incorporation into the habitat design would also greatly lessen the mass of the habitat and require a limited amount initial work for the astronauts upon arrival.

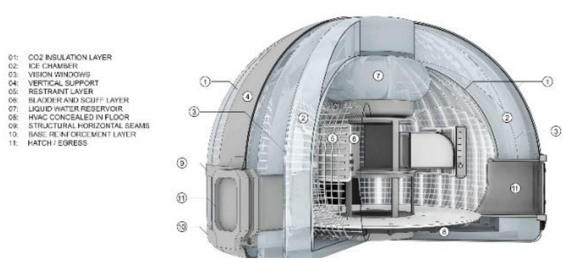

Fig. 5 Cloud Architecture Mars Ice Home [8]

In the same way that an igloo is created, Fig 5 shows that a layer between the outer and internal chamber of the habitat could hold ice water as a radiation shield [8]. This not only creates a sturdy and protective habitat, but also one that can be compact and become structural strong upon inflation.

2. Surface Regolith

Radiation shielding should be easily available on Mars so that extra weight is not needed when shipping the habitat. The most prominent source of shielding material is Mars regolith. Soil covers the whole planet and is exceptional at protecting against radiation. When designing the habitat, channels and depressions could be implemented so regolith could be placed. To create a successful layer of protection only 0.5m of regolith would need to be obtained [6]. This makes it extremely quick to create a layer of shielding with only uses Martian resources.

Fig. 6 AI Space Factory MARSHA [9]

Since Martian soil is so efficient at protecting against radiation, complete habitats could be made by 3D printing. AI Space Factory's MARSHA seen in Fig. 6 has shown that Martian soil mixed with a binder could be used as a "concrete" and create buildings that take various shapes [9]. This would allow for Martian Architecture to expand and create its style without being limited by standard habitat designs that focus on being compact.

3. Living Underground

Mars itself provides the materials necessary for radiation shielding. In the past humans have made underground shelters to protect themselves from nuclear fallout. Many of the same solutions can be applied to habitats on Mars. Lava tubes cover the planet where lava had previously dug through the surface. They now leave caves with ceilings that can block out radiation.

Fig. 7 National Geographic Rendition of Lava tube Habitat [10]

Inside lava tubes, humans will not have to worry about the high levels of radiation. This would allow for the habitats to be inflatable, thus making them dramatically lighter. For a large-scale colony, this would allow for a multitude of inflatable habitats to be transported from Earth instead of one that requires added radiation shielding.

B. Extreme Temperatures

1. Fibrous Insulation

Much like the normal fibrous insulation used on earth, these can be used on Mars in habitat design. They are relatively lightweight and provide enough thermal insulation from the outside to keep the crew inside warm. Fibrous insulators work well on Mars due to their lower thermal conductivity; this is a positive effect of Mars' low pressure [11]. Insulators however must have heat to insulate, which will come from a combination with HVAC systems and any other heat created by the running of equipment inside the habitat.

2. Aerogel

Silica Aerogel after being created was known for its incredible insulation properties. Since then, it has been used on spacecraft, satellites, and landers as a way of protecting electronics from intense heat and cold. What makes aerogel such a good thermal insulator is the composition of nanopores that inhibit air from moving eliminating conduction and convection as a mode of heat transfer [11]. This same material can be used in the design of future habitats as a way to insulate humans from the outside weather.

C. Production and preservation of Key Resources

1. MOXIE Oxygen Instrument

Inside of a populated habitat, the oxygen levels will eventually go down without an external source either creating new oxygen or scrubbing exhaled carbon dioxide. In addition to normal HVAC systems, a habitat must implement instruments that can provide humans multiple sources of oxygen.

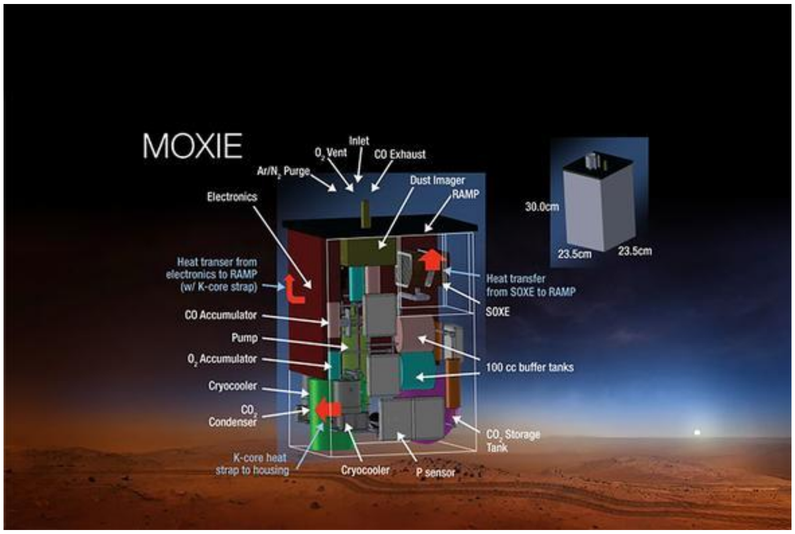

Fig. 8 MOXIE Oxygen Instrument [12]

Launched on NASA's perseverance rover was the MOXIE oxygen instrument that would test the feasibility of converting Martian CO2 into breathable air. It does so by collecting CO2 and then electrochemically splitting the molecules into oxygen and carbon dioxide [13]. Implementing designs such as MOXIE would allow the colony to be self-sufficient in creating new oxygen and would have a higher likelihood of surviving scenarios where oxygen could become scarce.

Though production of oxygen is important so is preserving the oxygen that has currently being produced. After the exhalation of CO2, this can create a build-up over time, which will eventually create a CO2 rich environment that can be deadly to humans. CO2 scrubbers must be incorporated into the design of the habitat in such a way as to minimize this. For decades lithium hydroxide canisters and more recently zeolites have been used to remove and store the CO2 from the habitat's environment. Though this provides a solution to CO2 buildup, valuable oxygen is being lost in this process. Being able to have multiple MOXIE systems that not only create oxygen from the Mars atmosphere, but purify the habitat's air would allow for multiple forms of oxygen to supply a colony.

2. Wastewater Usage and Purification

Currently, the ISS uses a water collection system to use all sweat and wastewater that is collected from the astronauts. This contaminated water is then purified into drinkable water. On Mars, this same system would have to be implemented as a way of conserving water that is not readily available. For the first few missions, much of the water used by astronauts would have come from earth or created by them. To save this valuable resource, the habitat must be designed in a way that looks to conserve the resource.

3. Use of Plants in Habitat Design

Plants have the ability to purify air, water, and also supply food for humans. Incorporating plants into the architecture of the habitat would create an ecosystem that mimics that of Earth. Plants would be able to take the load of creating oxygen and CO2 along with other instruments such as MOXIE. This would supply a stable source of oxygen for the habitat that would not suffer from mechanical failure. Some Aquatic are able to purify the water that they live in. The building could be designed in such a way that the channels for wastewater transport would travel along aquatic plants that become a stage filter before true purification. This wastewater would also be able to supply the plants with the nutrients that they need to grow and become food for humans.

Fig. 9 Artist Depiction of Martian Greenhouse [14]

Since water is such a scarce resource on Mars, adopting forms of plant growth such as hydroponics shown in Fig. 9 would allow for more water to be conserved in crop production [14]. The addition of plants into the design of the habit such as through wall-mounted gardens would be able to preserve and create many resources at one time.

D. Psychological Effects

Creating a building that has spaces of comfort for humans and brings back feelings of “home.” The first humans to venture to Mars will be the test subjects as to how the brain reacts to being separated from its original home planet. Though psychological studies have been done on astronauts who have spent days on the moon or months in space, none have experienced what the first Martian’s will. To keep these humans mentally sane and happy, the design of the habitat must facilitate that. The habitat must offer a space for humans to create a home in. It cannot look sterile and cold, but must be reminiscent of earth-like qualities. There must be places for astronauts to create memories with one another and bond over shared experiences. Inside there must be social “spaces” to support every group of people and community.

Fig. 10 Depiction of Martian Habitat, by Phil Smith [15]

The spaces that these astronauts will live in must be accompanied by lightning and plants as shown in Fig. 10. Natural sunlight will lighten up the interior of the habitat making it feel more earth-like. Plants will also become an integral part of the social structure of Mars. Plants will not only be a reminder of the home from which everyone came from, but be a symbol of the life source that humans wish to bring to Mars [15].

V.Conclusion

For all of Humanity's existence, it has only known Earth as a home. Adopting Mars as a secondary planet provides many challenges that threaten the lives of those people willing to live there. However, though there are many dangers there are many ways that they can be overcome. For a long-term colony on Mars, using architecture to incorporate solutions to these problems into the design of the habitat is the best way forward. The habitat should look to solve extreme radiation by using pile regolith and 3D printed structures. This provides an effective source of protection, but is also simplistic in the work needed to protect a shelter. Lava-tubes would eventually provide a great alternative, but are unrealistic in their manufacturing requirement for initial societies. Though the cold temperatures are extreme on Mars, the inability to efficiently transfer heat through its low-density atmosphere allows for the use of normally insulation techniques. Without adequate air, water, and food, the colony will not make it far. Using instruments such as MOXIE, to clean and produce air will ensure that the society can survive on its own. Plants should also be used not only as an addition to the water and air purification, but also as a key resource for the colony's food supply. Once humans can be taken care of physically, the architecture of the habitat must work to retain their mental stability. Social "spaces" must be created so the norms of society do not change from Earth, this will ensure both a strong community bond, but also the creation of a new home. Only until astronauts are able to make the habitat their own and begin to create memories inside it will it become a home to the people who inhabit it.

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